Desert Research Institute

HYDROLOGIC RESPONSES TO CLIMATE CHANGE IN THE LAKE TAHOE BASIN

EXECUTIVE SUMMARY

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BACKGROUND

Climate change is already impacting the Lake Tahoe Basin and even more change will come in coming decades. In response, agencies and communities throughout the Basin are beginning to develop plans and actions to enhance their capacity to adapt to climate change. An early step towards adaptation was an integrated vulnerability assessment in 2018 that provided state-of-the-science information on how climate is likely to change and how these changes will impact the Tahoe environment. However, the spatial resolution of climate and hydrologic projections available at that time was relatively coarse, and the present study provides a new set of more highly resolved projections of snowpack and streamflow responses to climate changes.

The new projections provided here are detailed enough to represent contrasts and commonalities across the diverse hydrologic settings of the Basin more completely than previous studies, and thus are an opportunity to anticipate future trends and transformations in the Basin, as well as climate-change hotspots and refuges in ways not possible with previous projections.

METHODS

For more than a decade, the Desert Research Institute (in collaboration with the U.S. Geological Survey) has been developing hydrologic models of the watersheds, streams, and groundwater systems that encircle Lake Tahoe. The resulting Precipitation-Runoff Modeling System (PRMS) model–used here–has the advantage over simulations used by earlier assessments that it simulates hydrology at highly resolved, 1/29-square-mile grid cells compared

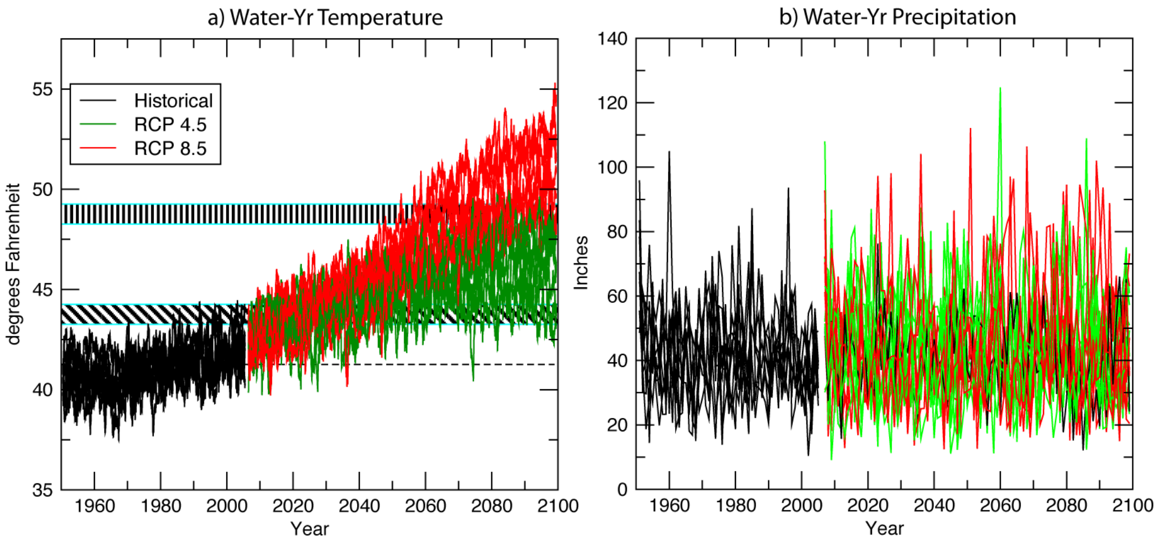

Figure E.1. Ensemble of projected changes in (a) air temperatures and (b) precipitation totals, over the Upper Truckee River subbasin, as an example of the changes projected by eight climate models downscaled and run through the basin PRMS model. RCP 4.5 greenhouse-gas emissions are less than RCP 8.5 emissions, especially after mid 21st Century. Hachured horizontal bars in (a) indicate warming of 2-3ºF and 7-8F warmer than the 1971-2000 historical norm (dashed line).

to the 14-square-mile grid cells used in the most recent previous assessment. Results from the PRMS model are typically output for each of 60 subbasins that together comprise the Tahoe Basin and represent all the various streams that flow into the Lake. Following an analysis to determine how well the PRMS simulates various aspects of Basin hydrology (more on this below), downscaled 1950-2099 climate-change projections from eight global climate models (GCMs) responding to two different assumptions about future global greenhouse-gas emissions (labeled RCP4.5 and RCP8.5) were input to the PRMS model to simulate an “ensemble” (or collection) of plausible hydrologic responses. A probabilistic ensemble approach is used here because we have little or no way to determine which of the GCMs to “believe” most, or even what emissions will look like in the future, so that a focus on ranges and averages of possible impacts is the safest approach. The simulated hydrologic responses to these 16 climate-change projections, and summaries of their statistics, are the principle products of the present study.

RESULTS

The full report describes projected changes in:

- average temperatures
- heat waves
- total precipitation
- timing of precipitation
- precipitation extremes
- April 1 snow-water amounts
- snow-season lengths
- total snowmelt
- snowmelt timing
- streamflow totals
- streamflow timing
- streamflow extremes
- rain-on-snow events.

The complete and detailed projections are being made available online so that interested parties will be able to do their own analyses and develop their own conclusions and uses for the new projections.

Some key results from the full report follow:

Climate Changes

Projected warming and changes in precipitation totals (expressed as changes from historical norms at subbasin scales) are spatially fairly uniform across the Lake Tahoe Basin. Climate responses to increasing greenhouse-gas concentrations in the global atmosphere are, after all, global phenomena acting over distances and times far larger than the Tahoe Basin and most individual weather events. Consequently, most of the subbasin-to-subbasin variations in hydrologic responses reported here are reflections of the ways that the different terrains, forest covers, and soils in the various subbasins repond to fairly similar climate changes.

Overall, by end of century, temperatures are projected to increase by about +4ºF to +9ºF with large warming in response to greater greenhouse-gas emissions (RCP8.5; Figure E.1a), as also in the California Fourth Climate Change Assessment Sierra Nevada Region Report (2018). Annual precipitation totals are on average projected to increase (in the ensemble of climate models evaluated here) by about 0 to 15%, depending on emissions (Figure E.4). However, these ensemble-average precipitation changes differ considerably from climate model to climate model, and are small compared to the range of historical year-to-year precipitation variations, indicating that the long-term annual-precipitation changes will very likely be well within the large range of historical variations that we already are used to. Thus the projection that precipitation will increase overall ends up being the least confident projection by this study.

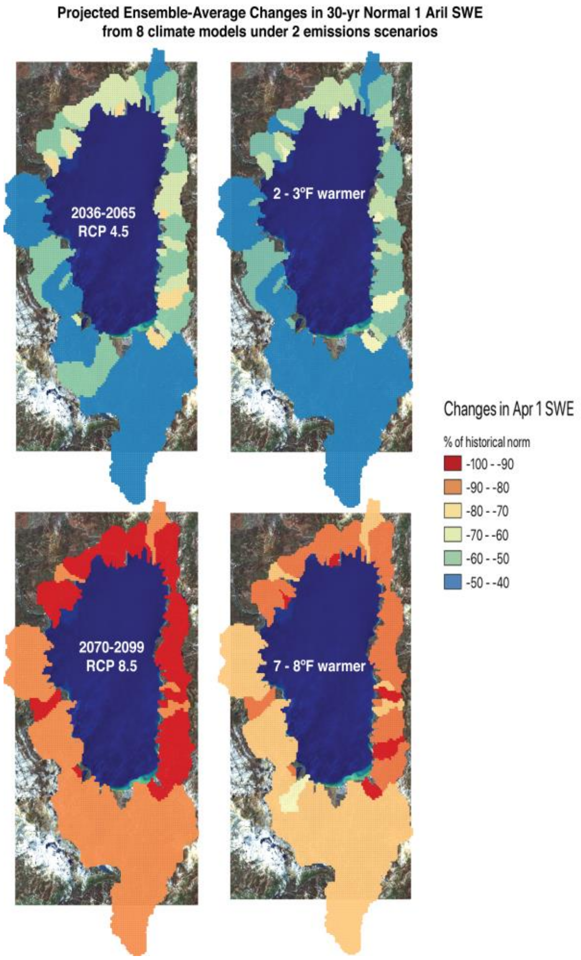

*Figure E.2. Ensemble-average declines in 30-yr normal April 1 snow-water equivalents over the Tahoe basin, as projected by eight climate models downscaled and run through the basin PRMS model (left) and for nonoverlapping 30-yr segments from the overall ensemble with average warming in the hachured ranges in Fig*ure *E.1a (right). Percentage of normal is reported such that "+90%" means the future value is 1.9 times the historical norm.*

On the other hand, precipitation extremes, like annual maximum 1- and 3-day precipitation totals, are projected to increase by about 10–25% depending on the future emissions assumed. These increases in precipitation extremes are smaller than the scatter between GCMs, indicating significant agreement among models, making this a reasonably confident projection.

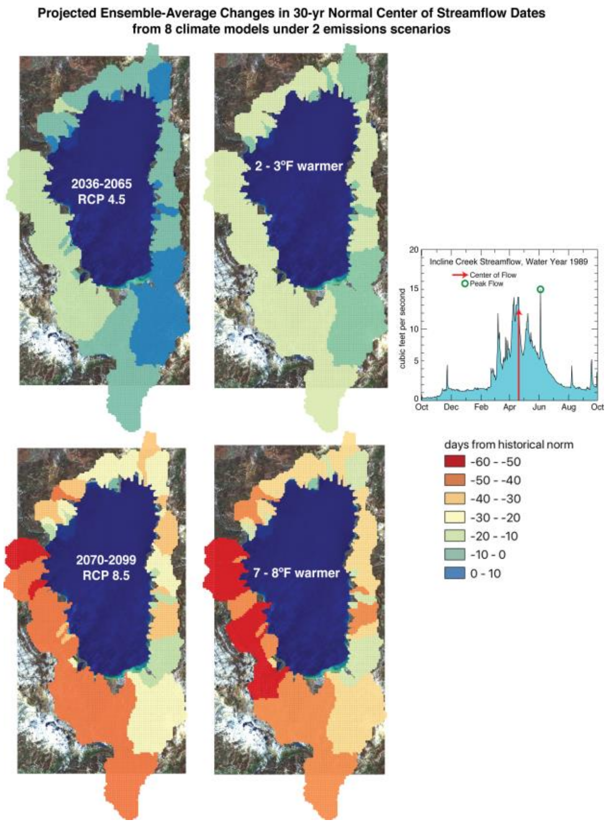

Figure E.3. As in Figure E.2 except for "center of streamflow" timing changes *(see inset for example comparison of center of streamflow vs. annual maximum-daily flow timing for observed flows in Incline Creek).*

Snowpack Changes

In response to the projected warming, large snowpack declines are to be expected. April 1 snow-water equivalents (SWEs) and annual snowmelt totals (as a simple measure of how much snowpack forms overall) decline substantially in the projections, with the greatest declines in subbasins along the north and east sides of the Lake (Figure E.2). April 1 SWEs all but disappear in the northern and eastern subbasins and decline by about 80% in the rest of the Basin when future emissions are large (RCP8.5). This decline reflects projections of less snowfall and snowpack overall as well as of earlier snowmelt. Snow-season lengths are projected to be a month to more than three months shorter by end of century, depending on location and emissions, and the "center" of snowmelt timing arrives about 20 to 50 days earlier in the year. Precipitation timing is not projected to change much but, mostly because of the warming-induced snowfall and snowmelt changes, the center of streamflow timing is also projected to arrive about 20 to 50 days earlier on average (Figure E.3), in agreement with more coarsely resolved "North Sierra" projections in the California Fourth Assessment Sierra Nevada Region Report (2018) and in most previous studies.

Streamflow Changes

Annual streamflow totals do not decline on long-term average, despite increasing overall evaporative demands (i.e., atmospheric "thirst"). Indeed, flows increase overall (Figure E.4), reflecting a combination of the modest ensemble-average precipitation increases (Figure E.4) and the fact that much more future runoff occurs before the summer upturn in the atmospheric thirst for evaporation and plant transpiration. The largest streamflow increases are projected for the east side of the Lake. Year-to-year streamflow fluctuations also grow (not shown here), resulting in increased episodes of hydrologic whiplash between drought conditions and flood.

Annual streamflow maxima (peak flows) are projected to increase considerably with maximum 3-day flow totals in a few subbasins almost tripling by end of century under the greater RCP8.5 emissions. More typically, peak flows increase by about 30% to almost 150% of their historical averages (right maps in Figure E.5). These large increases in flood flows reflect the more extreme storms (left maps in Figure E.5) but are amplified versions of those precipitation extremes because more high-altitude catchment areas receive rainfall rather than snowfall in the warmer future storms.

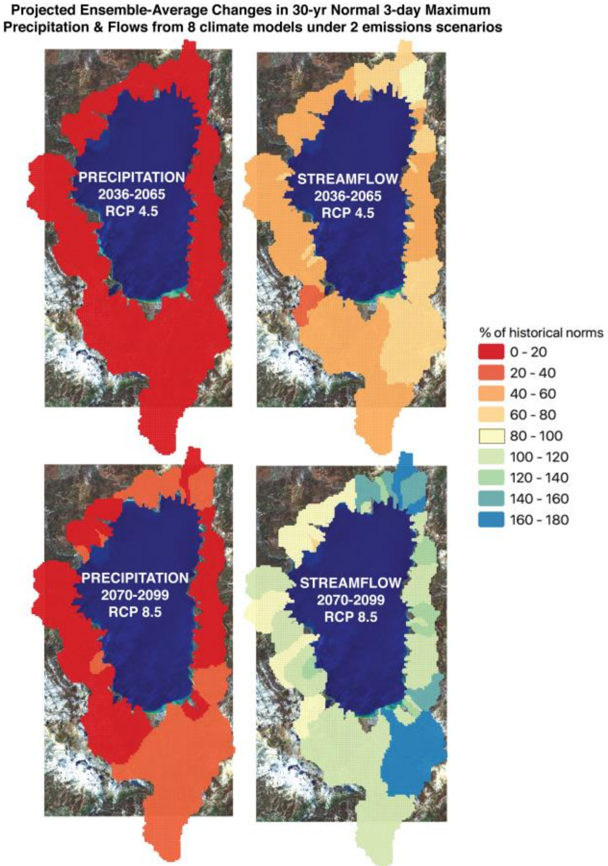

Figure E.5. As in Figure E.4 except for changes in 3-day maximum precipitation (left) and streamflow (right).

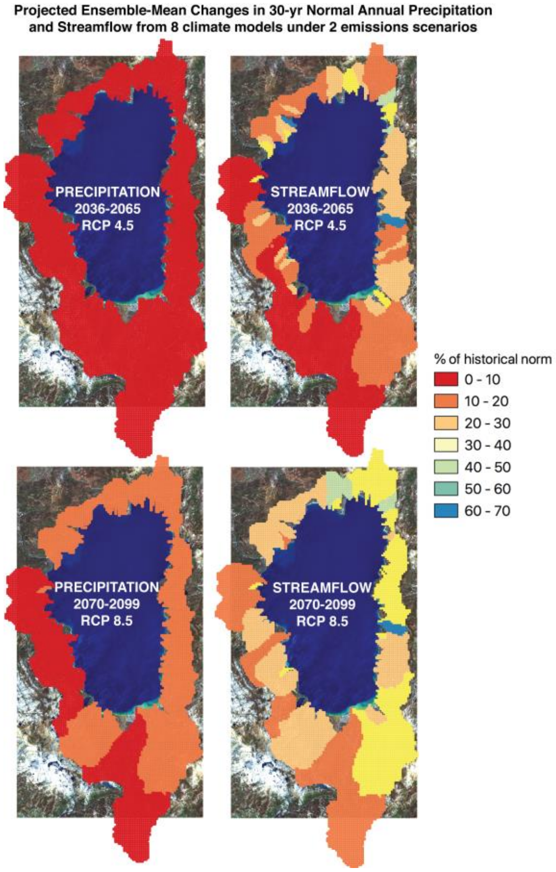

Figure E.4. As in left side of Figure E.2 except for changes in annual precipitation (left) and annual streamflow (right).

These projected increases mean that more flow will enter the Lake at higher rates in shorter periods of time; that is, inflows to the Lake will be concentrated into shorter, more intense bursts overall, potentially challenging some sediment- and nutrient-inflow management efforts, all other things being equal.

Hot Spots and Refuges

Each of the subbasins responds to climate changes in its own way, reflecting distinctive elevations, aspects, distances from the main ridgeline of the Sierra Nevada and thus precipitation regimes, forest patterns, and so on. Subbasin responses differ in terms of their changes in snowpacks, streamflow totals, and flood regimes. For planning purposes, it will be useful to be able to distinguish which subbasins are more vulnerable overall to climate change and which are less so. Such distinctions could provide a basis for deciding where to invest to hold the line against future changes ("hot spots"), versus areas where relatively muted future changes might provide some refuge against the worst climate-change impacts.

An example of such a "hot spot versus refuge" mapping is shown in Figure E.6, where projected percentage- or days-of-year changes (e.g., from Figures E.4 and E.5) at each of the 60 subbasins were ranked separately for each of 10 measures of climate-change response. Then at each subbasin the 10 ranks were averaged to distinguish the overall most-responsive subbasins from less-responsive subbasins.

Overall, subbasins on the north and east sides of the Basin respond more than the west and south sides. At a finer scale, for this 30-yr period and the higher emissions scenario, Trout Creek in the southeast corner of the Basin, and Mill Creek in the Incline Village area, are subbasins that are most impacted on average and might be examples of hot spots for climate change. Eagle and Cascade Creeks near Emerald Bay are projected to be least impacted overall. Results of hot-spot determinations will depend on the particular decades and emissions analyzed, as well as on the particular subset of impacts ranked but, in consultation with agencies of the Basin, hotspot-versus-refuge analyses can add geographic detail to planning and adaptation efforts.

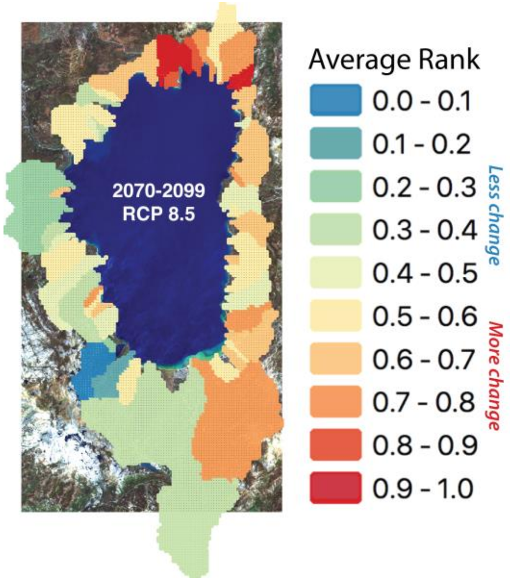

Figure E.6. Overall average of subbasin ranks of projected climate-change impacts in the Tahoe basin by end of 21st Century under RCP8.5 emissions. Measures included in this calculation are the projected changes of (1) annual precipitation, (2) maximum 3-day precipitation totals, (3) April 1 SWE, (4) snow-season length, (5) snowmelt timing, (6) annual snowmelt, (7) annual streamflow, (8) streamflow timing, (9) maximum 3-day streamflow totals, and (10) amount of rainfall on snow. Measure-by-measure, the subbasin responses are ranked from smallest to largest, and then all the ranks for each subbasin are averaged to arrive at a single average ranking for the subbasin. Then those average ranks are rescaled from 0 (subbasin with lowest average rank) to 1 (subbasin with highest average rank).

LIMITATIONS & WAYS FORWARD

As noted earlier, PRMS model errors were evaluated by comparing historical streamflow simulations to historical observations at nine stream gages around the Basin. The comparisons indicate that the PRMS model used here is capable of simulating streamflows around the Basin under a wide range of historical climatic conditions and during medium to high flows. The comparisons indicated that the model is probably not as capable of providing reliable low-flow projections, and so the present study could not confidently project changes in the low warm-season flows or soil- and fuels-moisture. A more inclusive, well-calibrated, groundwater-surface water model (e.g., the GS-FLOW model) will be needed for reliable projections of future dry seasons.

The simulations summarized here do not include hydrologic effects of forest changes under historical or climate-changed conditions (e.g., from past or future wildfires), but could—in principle--be modified to preliminarily explore such effects, if changes in forest cover were made available as externally-provided time-varying conditions to be imposed in the PRMS model.

A new generation of climate projections will become available in the next year or so for the upcoming California Fifth Climate Change Assessment. If the different generations of climate-change projections that have emerged for use in assessments since about 2000 is our guide, ensemble-average precipitation patterns may be expected to change somewhat and projected warming may increase modestly (as local temperature impacts of snow-cover loss are currently being integrated into the new projections). These changes in projections may modify hydrologic responses but, for the most part, the vulnerabilities emphasized in the present study are likely to remain broadly representative.